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PROGRESS REPORT

ENHANCED BOILING AND
CONDENSATION OF R-114

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INTRODUCTION

The U.S. Navy is interested in minimizing the size and weight of main propulsion components and auxiliary machinery equipment on board both submarines and surface ships. A strong motivation exists in contributing to this goal through the use of state-of-the-art heat-transfer enhancement techniques.

Recent advances in structured boiling surfaces have shown enhancement in the pool-boiling heat-transfer coefficients of up to a factor of 10 over the smooth-tube values [1, 2, 3]. When oil was present up to 10% by weight, the enhancement was seen to decrease, but these tubes still outperformed the smooth tube by a factor of 3 to 5 at all practical heat fluxes (< 40 kW/m^2). These results however were obtained with a single-tube apparatus, and may be different when tested in a tube bundle. Vapor-bubble agitation created by the lower tubes in a bundle is expected to enhance the performance of the upper tubes. On the other hand, the presence of too many bubbles could provide insufficient liquid to the upper boiling surfaces, thus decreasing the heat-transfer performance. In the presence of oil the above mechanisms may be substantially changed, so that a comprehensive series of data covering actual operating conditions is needed before these enhanced tubes can be used reliably in shipboard water chiller systems.

In addition, the Navy is interested in using titanium tubes in refrigeration condensers, as titanium provides two important advantages when used as the condenser tube material. First, titanium has a high strength/weight ratio compared to copper-nickel, which is the most commonly used material in naval condensers. Second, it is less susceptible to erosion and biofouling than copper-nickel or stainless steel. The major disadvantage of titanium is its low (about three times smaller) thermal conductivity compared to copper-nickel alloy. Therefore, it is important to evaluate the thermal performance of titanium enhanced surface tubes for condensation of R-114.

In support of the above goals, the Naval Postgraduate School has been conducting research to determine the best boiling and condensing surfaces for utilization in Naval R-114 refrigeration plants. A tube bundle apparatus was constructed during FY1987 to simulate a portion of an operating refrigeration plant evaporator and condenser. During FY1988, Professor Marto was on Sabbatical Leave in Europe and in July 1988, Dr. Wanniarachchi terminated his employment with the U.S. Government to accept a position at the University of California, Santa Barbara. As a result, due to the unavailability of thesis students, the program remained inactive until April 1988. At that time, Lt. B. Mabrey commenced modifying the apparatus to ensure its proper operation and to instrument it for accurate measurements. This project report briefly describes these activities.

EXPERIMENTAL APPARATUS

The experimental apparatus is depicted schematically in Figure 1. Figure 2 shows the details of the test condenser and evaporator, while Figure 3 is a photograph of the entire apparatus and supporting systems. The boiler/condenser unit was fabricated from stainless steel plates to withstand an absolute pressure of 308 kPa. The condenser is 1.30 m long with an external diameter of 0.61 m and an effective condensing length of 1.22 m. The condenser chamber has five view ports to provide top to bottom views of the test tubes at various locations along the effective condensing length.

The condenser chamber is attached to the boiler chamber by a rolled stainless-steel cylinder located mid-way along the condenser chambers's length allowing condensate to drain by gravity. The boiling chamber was also fabricated from rolled stainless-steel and is cylindrical with an outside diameter of 0.61 m and a length of 0.279 m. The boiling chamber is fitted with two view ports for observation during operation. The boiling unit is comprised of three groups of tubes as shown schematically in Figure 2. In the simulation tube bundle, there are five boiling tubes each nominally rated at 1.5 kW. In the auxiliary tube bundle, there are four boiling tubes each nominally rated at 4 kW. The instrumented tube bundle is comprised of 35 tubes, with 10 active boiling tubes rated at 1 kW each, 5 instrumented boiling tubes, and 20 dummy tubes. The power provided to these groups of tubes is controlled by three variac controllers. Details on the design and construction of the basic test platform are available in the thesis of Murphy [4].

Component equipment that support the R-114 tube bundle test platform include: (1) an R-114 storage and transfer system, (2) a condenser cooling and flow control system, (3) coolant and (4) an eight-ton refrigeration unit.

The R-114 storage and transfer system consists of a stainless-steel cylindrical tank 0.350 m in diameter and 0.91 m in length located on a rack above the coolant sump. Coolant and flow control to the test apparatus and ancillary equipment is accomplished by two different flow path systems which are driven by two 0.5 HP constant-speed pumps. The coolant for the test condenser tube bank passes from the pump discharge through PVC piping to a Plexiglas header. At the header, the flow is split and proceeds through Tygon flexible tubing to separate rotameters for each test tube. At the exit of the main condenser chamber, coolant leaves each tube and flows through flexible Tygon tubing to individual mixing chambers before returning to a central Plexiglas header and back to the main sump.

The coolant is an aqueous solution of ethylene glycol containing approximately 60 percent by weight ethylene glycol. It is chilled by an 8-ton refrigeration system that continually re-circulates sump coolant with a 0.75 HP pump. The refrigeration system is capable of maintaining a sump temperature between -21°C and ambient temperature.

WORK PROGRESS

During the period May through September 1988, Lt. Mabrey spent a great deal of time accomplishing the following:

a. Even though the previous students had made the apparatus leak-tight, during FY1987 and the early part of FY1988, the system had developed some leaks. In addition, the primary condenser tubes were not installed by the previous students, and the corresponding openings for these tubes had been blanked off. Lt. Mabrey made the necessary modifications and installed the four primary condenser tubes in a vertical column arrangement. Following these modifications, the system was made leak-tight.

b. Lt. Mabrey completed all necessary piping to the four primary condenser tubes, together with mixing chambers thermopile wells, etc.

c. Four thermopiles, each having ten series-connected junctions on either end, were manufactured and installed on the apparatus. In addition, single thermocouples were installed to measure coolant inlet temperatures to each of the four condenser tubes as well as vapor and liquid temperatures.

d. The four flow meters, through which the water/ethylene glycol solution flowed, were calibrated. This calibration was performed at two coolant temperatures (-20 and -7°C).

e. The operation of the R-114 liquid reservoir was redesigned and it was installed over the large coolant sump. A cooling coil was provided inside the R-114 reservoir so that transfer of R-114 liquid to the reservoir could be achieved by actually transferring vapor and condensing inside the reservoir.

f. The apparatus, coolant sump and all piping were insulated with thick, foam-rubber sheets and tubes.

g. All necessary instrumentation was provided, and the development of the computer software for acquiring and analyzing the data was begun.

SUMMARY

During FY1988, the tube bundle apparatus was inactive until the latter part of the fiscal year. Lt. B. Mabrey spent a considerable amount of time modifying the apparatus, improving upon its design and operation, ensuring its vacuum-tightness, installing all instrumentation and preparing the data-acquisition and reduction software.

The system is ready for preliminary testing and data should be gathered during the first quarter of FY1989.

REFERENCE

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2. McManus, S.M., Marto, P.J. and Wanniarachchi, A.S., "An Evaluation of Enhanced Heat Transfer Tubing for Use in R-114 Water Chillers," HTD-Vol. 65, ASME, pp. 11-19, 1986.

3. Wanniarachchi, A.S., Marto, P.J. and Sawyer, L.M., "Effect of Oil on Pool-Boiling Performance of R-114 from Enhanced Surfaces," 2nd ASME-JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, 1987.

4. Murphy, T.J., "Pool Boiling of R-114/Oil Mixtures from Single Tubes and Tube Bundles," M.S. Thesis, Naval Postgraduate School, Monterey, California, September 1987.

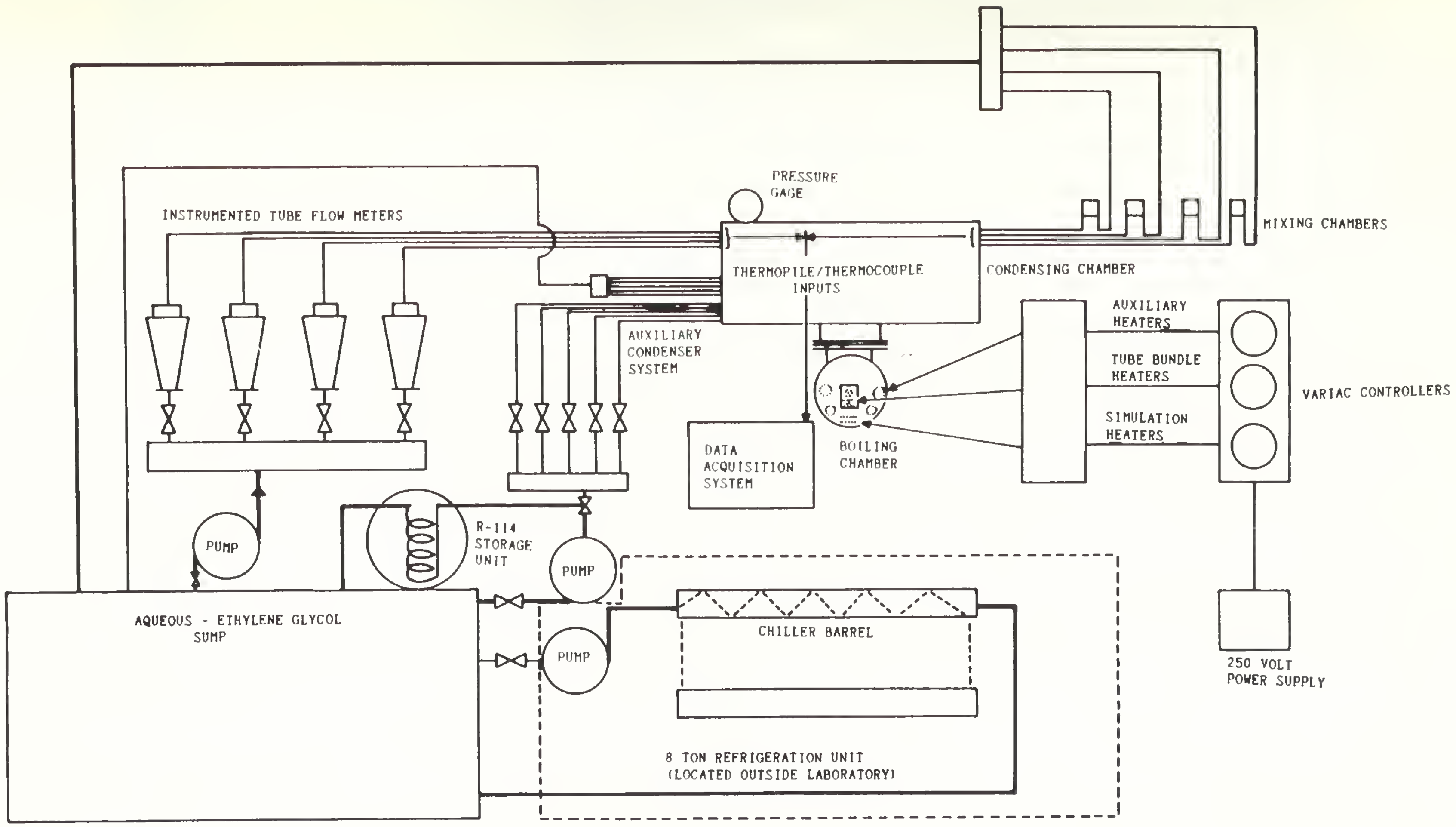

Figure 1. Schematic of Experimental System

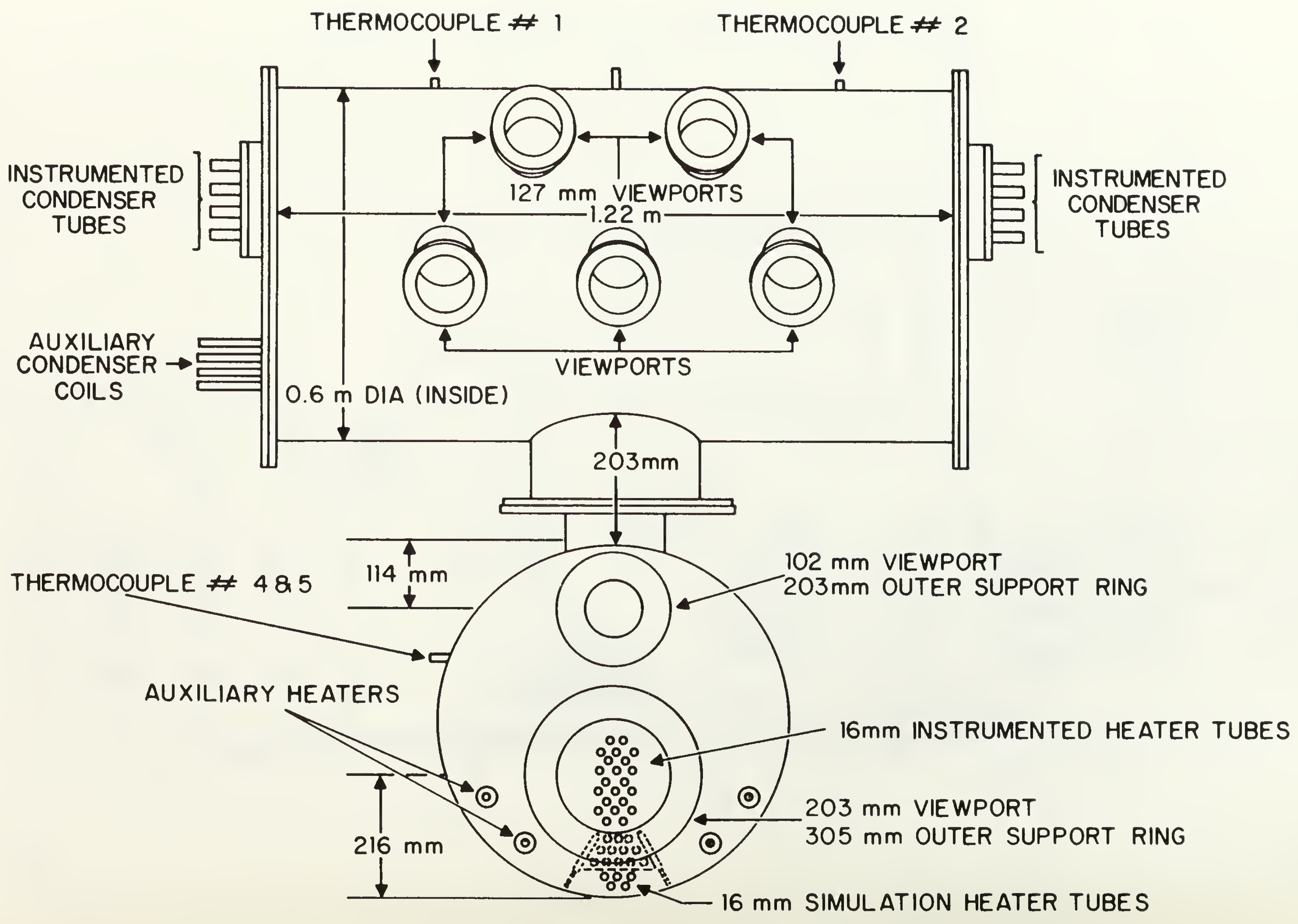

Figure 2. Sketch of Boiler/Condenser Apparatus

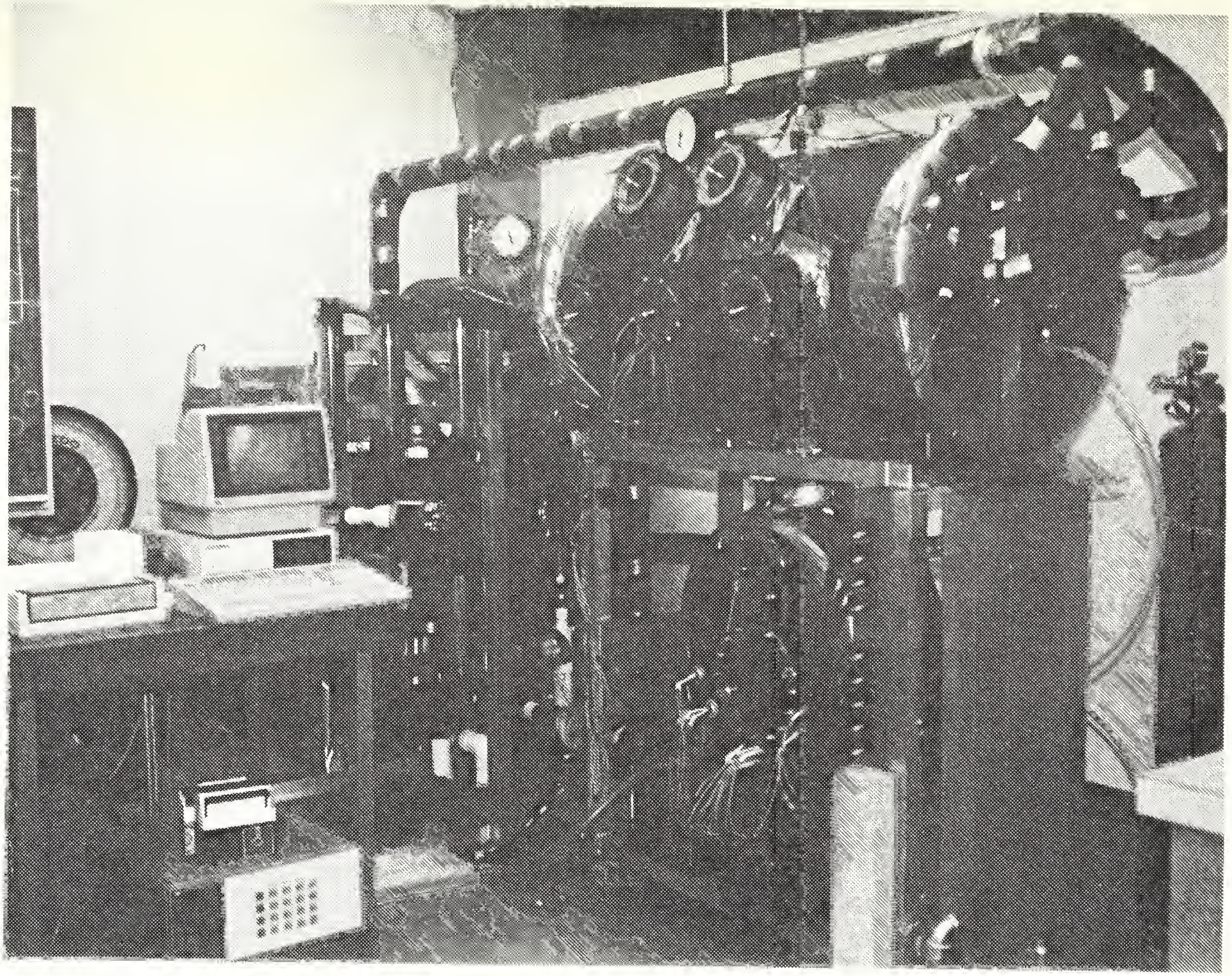

Figure 3. Photograph Showing Overall System

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